Modern compact star observations and the quark matter EoS

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Abstract

A hybrid equation of state (EoS) for dense matter is presented that satisfies phenomenological constraints from modern compact star (CS) observations which indicate high maximum masses ($M \sim 2M_\odot$) and large radii ($R > 12$ km). The corresponding isospin symmetric EoS is consistent with flow data analyses of heavy-ion collisions. The transition from nuclear to two-flavor color superconducting quark matter at $n_{\rm crit} \sim 0.55$ fm^{-3} is almost a crossover.

Constraints on the high density EoS emerge from analyses of the elliptic flow in heavy ion collisions (HICs) and astrophysical data regarding the mass and mass-radius relations of neutron stars. Altogether they form a valuable benchmark for the reliability of a given model EoS as exemplified for a set of modern nuclear EsoS in [1] with the result that every EoS fulfills some of these constraints but none could satisfy all of them. In the following a subset of these constraints is applied in order to investigate the compatibility of the presence of a quark matter core in the neutron stars interior with present phenomenological findings.

The stiffness of the symmetric EoS is limited by analyses of the elliptic flow in HICs [2] as indicated by the hatched area in the right panel of Fig. 1. The left panel of Fig. 1 illustrates the astrophysical constraints applied in this paper. The object PSR J0751+1807 gives a lower limit on the maximum NS mass of $\approx 1.9M_\odot$ [3], whereas the thermal emission of RX J1856-3754 provides a lower limit in the mass-radius plane, which suggests minimal radii of $R > 12$km for expected NS masses [4]. These latter three constraints form a *minimum requirement* on a reliable hybrid EoS.

It has been questioned whether they could be compatible with a phase transition to quark matter, which is expected to sufficiently soften the EoS and thus lowering the maximum NS mass. In [5] a set of counter examples has been provided. Here we discuss a hybrid EoS where the quark matter phase is described by a color superconducting 3-flavor NJL model [6] augmented by a selfconsistent vector meanfield responsible for stiffening the EoS [7]. The nuclear matter phase is described within the Dirac-Brueckner-Hartree-Fock (DBHF) approach [8]. Both pure NSs and those with a quark matter core are consistent with modern CS constraints, see Fig. 1. A lowering of the transition density results from increasing the diquark coupling strength, without affecting the stiffness, i.e. the maximum mass. Note that the transition to the color-favor-locking (CFL) phase renders the hybrid star unstable [7, 9].

Since the transition from the nuclear to these stiff QM EsoS is almost a crossover with only a tiny density jump, the resulting hybrid EoS is barely distinguishable from a purely hadronic one. The corresponding hybrid stars “masquerade” as ordinary neutron stars [10] regarding their masses, radii and similar observables of compactness. “Unmasking” the NS interior could be possible by analysing the cooling behavior [11] which eventually discriminates nuclear from quark matter interiors due to the role of the pairing gaps [12, 13, 14].

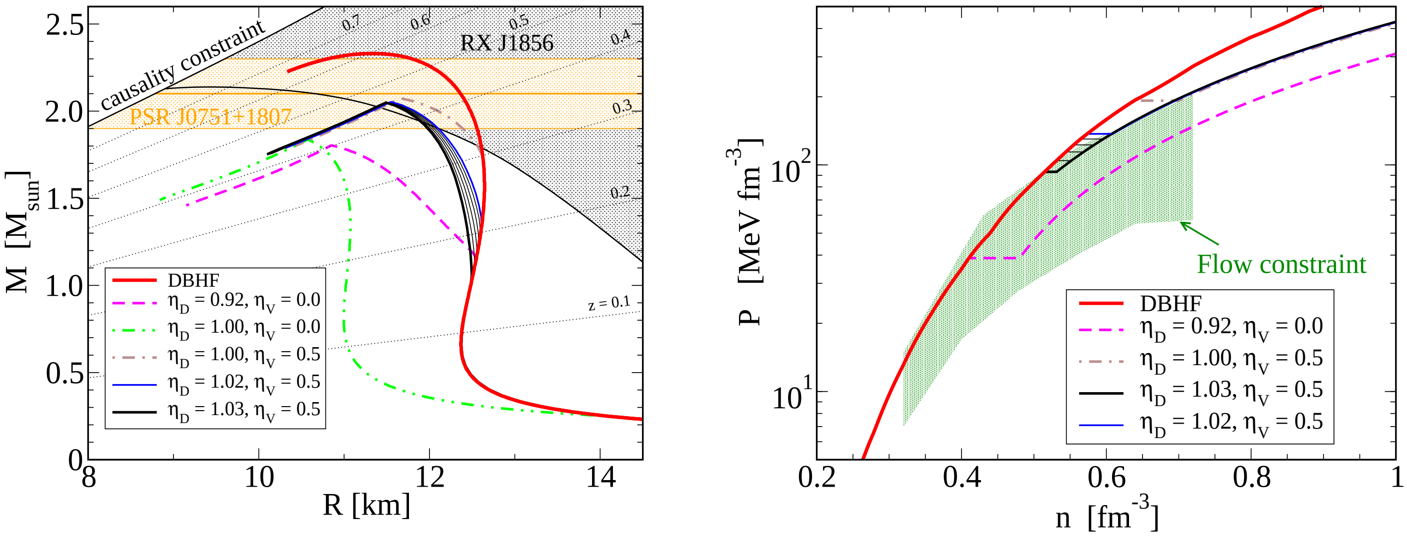

Figure 1: Hybrid EoS stiff enough to fulfil mass-radius constraints from PSR J0751+1807 and RX J18056 (left panel) but also soft enough to satisfy Danielewicz' flow constraint (right). A large vector meson coupling (η_V) increases the stiffness at high densities and thus the maximum mass, whereas increasing the diquark coupling (η_D)lowers the onset of the deconfinement transition density and thus the critical star mass.

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